A Wireless Internet-Based Observatory: The Real-time Coastal Observation Network (ReCON)

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Abstract* - ReCON, a coastal observation network with nodes on Lakes Michigan, Huron, and Erie, has been designed to allow flexible deployment of coastal access points and simplified integration of sensor packages. The system provides continuous observations of chemical, biological, and physical parameters, facilitates modification of sampling parameters in anticipation of episodic events, facilitates collection of field samples in response to episodic events, supports long term research and contributes to sensor and system development. The system currently supports projects addressing harmful algal bloom (HAB) detection, human health observations related to beach closures and drinking water processing concerns, rip current warnings, integrated ecosystem assessment, and public access to historic shipwrecks at the Thunder Bay National Marine Sanctuary. ReCON system development relies on wireless broadband technology and a network-based underwater hub designed to allow expansion via satellite nodes. The system architecture allows simplified integration of sensors from various institutions through guest ports. Access to and control of instrumentation is made available to the scientific community and educational institutions through the internet. A real-time database management system provides data and information for forecast model initial conditions, forecast verification, public information, and educational outreach.

The technology demonstrated on the ReCON project represents an important contribution to the success of regional coastal ocean observing systems. The pervasiveness of wireless internet technology in coastal regions represents an opportunity to significantly expand high bandwidth coastal observation capabilities. Implementing ReCON on a regional coastal level in the Great Lakes has contributed to better tools and understanding for managers and educators, more on-water observations for marine forecasters, and improved scientific measurements.

I. Introduction

The development and application of coastal observing systems is a major national need identified by Ocean.US [1]. Real-time observations are needed to provide forecasters, researchers, coastal resource managers and the public with information on the current status of the ecosystem, increase marine safety, reduce public health risks and provide information to improve and validate operational forecasts [2]. A true national network of coastal observation buoys should be based on standardized and readily available technologies and provide an element of durability and portability.

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The ReCON project leverages existing internet technology to provide real-time data collection of a wide range of environmental parameters from seabed to sea-surface. The technology, applicable in any coastal region, currently consists of five coastal shore stations covering approximately 4300 square kilometers of sea surface (*Figure 1*). Observation nodes are distributed over a wide range of ecosystems representing oligotrophic to eutrophic conditions. The system provides the capability to deploy multiple Ethernet-based [3], portable buoys [4] or fixed stations within an approximate 24 kilometer radius from the shore station node. Surface wireless and wired underwater guest ports [3] can provide observations to a wide range of regional institutions without incurring the expense of a buoy development and deployment program. Access to guest data as well as standard physical observations is obtained through the established ReCON data collection infrastructure. Recent deployments have demonstrated the system's capacity to provide observations of and subsequent response to episodic events and to transfer high-bandwidth data such as imagery and video for research, operational, and educational applications [5]. The major components of the system consist of a control center, shore stations, buoys and permanent stations with surface sensors, and underwater hubs with sensors.

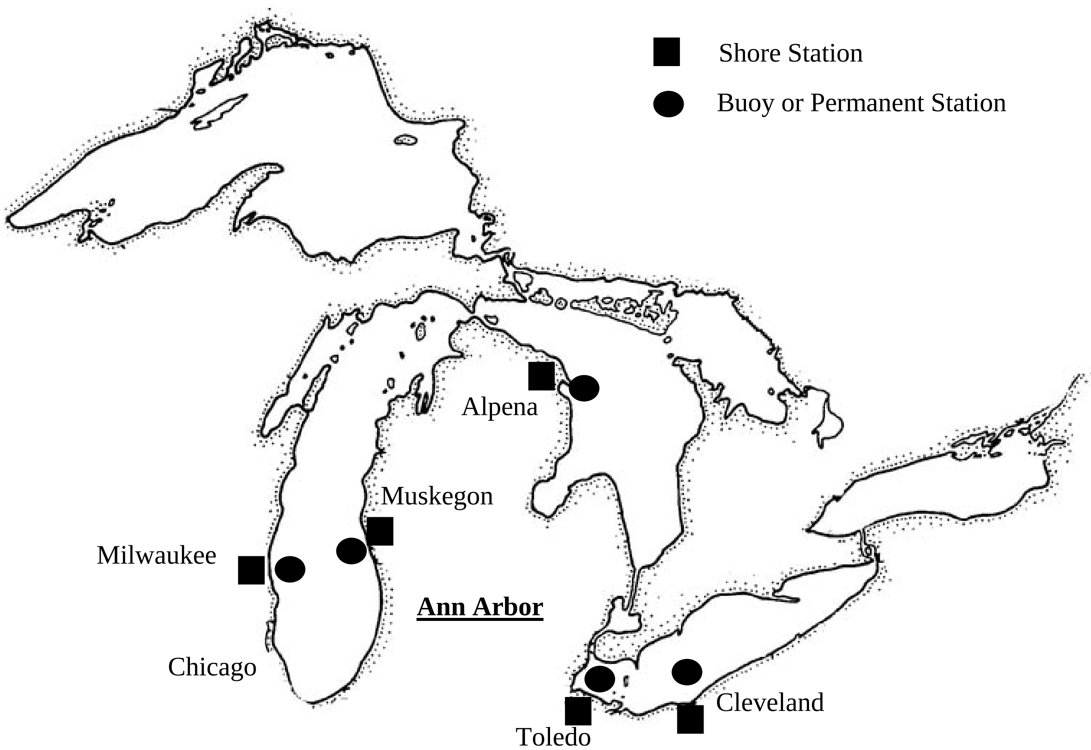

Figure 1. Current ReCON shore stations allowing buoy deployment within an approximate 4300 square km area. The Ann Arbor operations center controls data collection platforms and transfers sensor data for web display, archive, research, and forecast applications.

II. System Description

ReCON utilizes off-the-shelf technology to implement a surface communications network implemented with wireless IEEE802.11b/g radios (*Figure 2*). Within line of site, buoys will choose the shortest path to shore station nodes. System range can be extended beyond line of site by relaying data through a buoy within range of shore stations. Underwater hubs can be connected to additional hubs, with limited power. Maximum deployment range and system throughput vary depending on signal amplification and antenna heights.

The system block diagram in *Figure 3* provides a general overview of components required to transfer data from the sensor to a specific application, observing system web display or archival site. The sub-surface network also transfers control center commands for specific devices through a robust underwater Ethernet cable connected the underwater hub to the surface buoy.

Underwater instruments capable of serial communications are connected directly to an internet addressable serial port server. Analog sensors are connected to the network port server through an analog to serial converter.

Sensor data transfer software includes Linux shell and Kermit scripts to schedule and transfer serial data from instrumentation. These scripts are run on a Linux processor located on the surface buoy or in the underwater hub. Linux scripts (Bourne shell) and C-language programs are used to transfer and decode binary files from acoustic wave and current measuring instruments. Software commands to begin data collection are preceded with control commands to initiate sensor bio-fouling operations. All data collection is scheduled through a control file with a script used to clear the system watchdog timer.

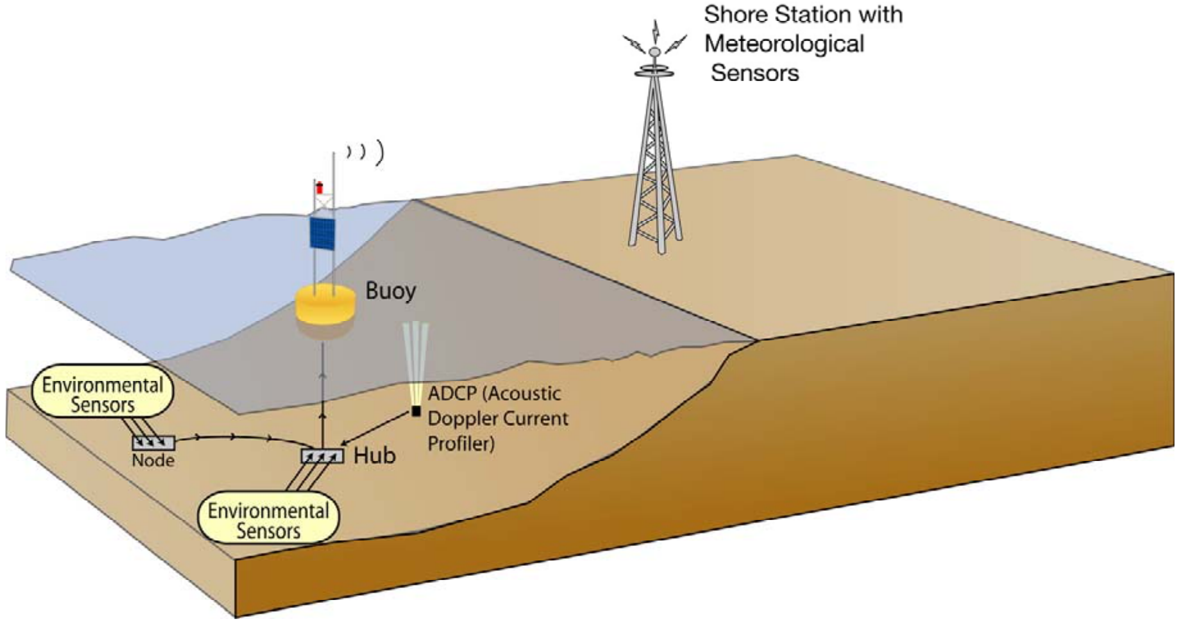

Figure 2. Conceptual illustration of the ReCON buoy and hub. The system is capable of providing a wireless Ethernet connection to offshore buoys and instrumentation up to 24 km from shore and buoy to buoy connections beyond shore station line of site.

The web-based data management system permits access to real-time marine conditions by forecasters, coastal managers, educators, researchers and the public. Data for these applications are stored on the buoy and at the shore station node until the control center Linux computer residing external to the firewall transfers data to the archive. Once data reaches the center it is pulled from archive to support forecast and research applications and update real-time web displays. The shell scripts supporting data transfer to applications are initiated from a Linux processor residing within the control center firewall to meet system security requirements.

Power to underwater hubs and instrumentation is controlled through low power, solid-state relays. Power control modules, uniquely designed for ReCON, are located on the surface buoy or fixed station and in underwater hubs. The solar/battery charging system is designed to stop charging when batteries have reached 14.1 volts DC. Lead-acid batteries utilized on ReCON are fully discharged at 10.3 Volts. To prevent damage, power management software monitors battery voltages shutting the system down at 10.5 volts. Linux scripts are used to monitor system power consumption and scheduled updates to control center engineering web displays.

Security is addressed with OpenSSH (Open-source Secure SHell), protocol 2, 3DES (Triple Data Encryption Standard) 168-bit encryption, as the means for all communications between the remote platform, shore station, and control center computers using a shared encryption key. The 802.11 wireless internet communications uses hidden SSID (Service Set IDentifier) and MAC (Media Access Control) address filtering. In addition, all computers incorporate firewalls restricting access to the specific public IP (Internet Protocol) numerical addresses assigned to center computers.

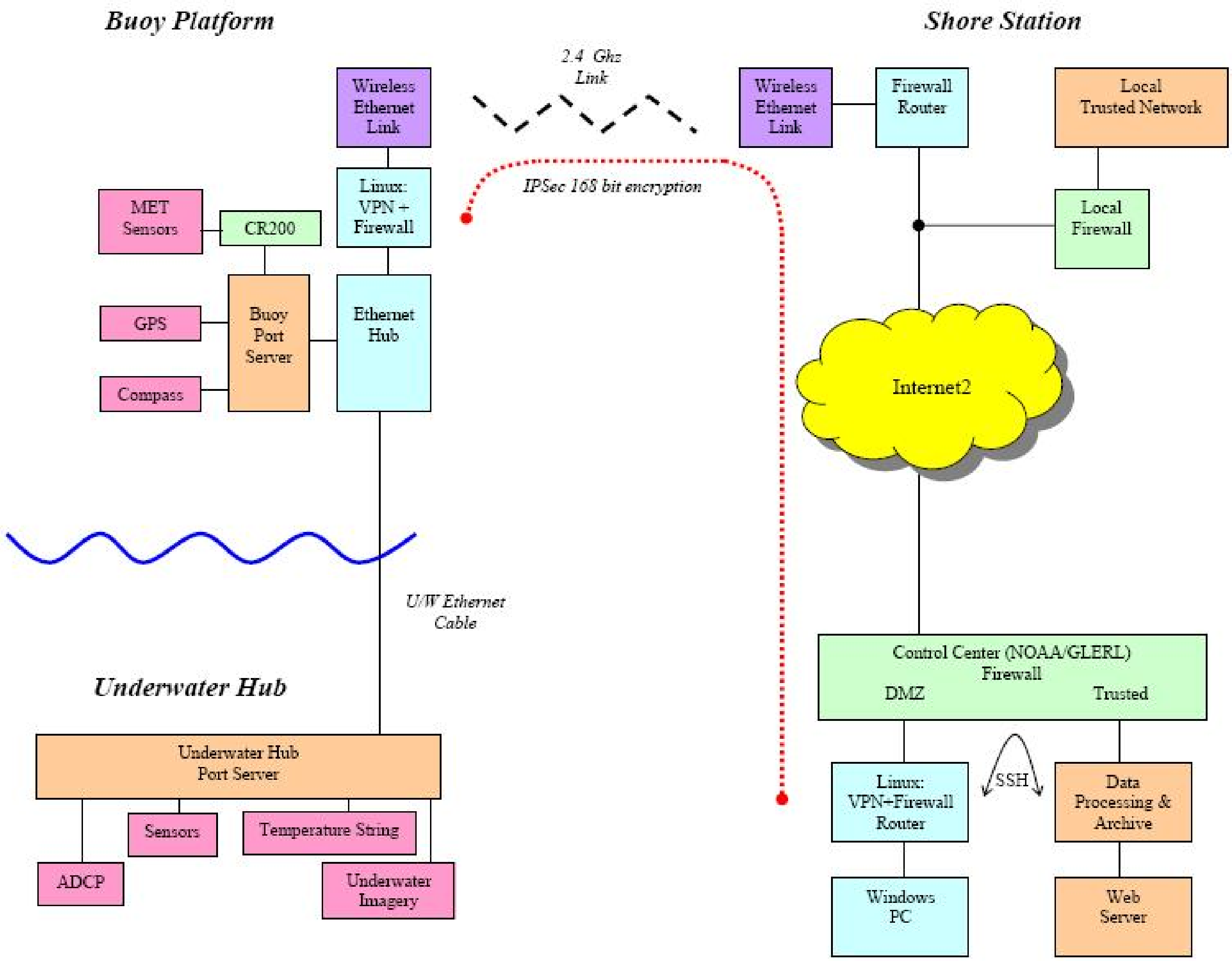

Figure 3. ReCON System Block Diagram

III. Present and Future Applications

Presently, ReCON offshore stations provide reliable real-time access to a wide range of sensors measuring parameters such as winds, air temperatures, waves, water temperature profiles, current profiles, chlorophyll, pH, photosynthetic active radiation, and dissolved oxygen. The real-time, high bandwidth design permits *in situ* testing of experimental platforms and sensors providing imagery, acoustic backscatter estimation, nutrient chemistry measurements and harmful algal bloom (HAB) observations. Observation systems currently support operational National Weather Service marine weather forecasts and experimental rip current warnings by routing sensor data through the National Data Buoy Center and through the ReCON website. Ecosystem forecast research related to hypoxia and HABs is currently supported through buoy nodes on central and western Lake Erie. Public high school students have gained unprecedented classroom incite into the influence of nutrient rich river inputs on hypoxia events on Lake Erie, using the system in class projects. The ability to transmit real-time audio and video has been used to provide "live dives" of archeological and scientific explorations to students nationally from NOAA's Thunder Bay National Marine Sanctuary.

Present ReCON capabilities will be extended to include the transmission of real-time digital video data from an offshore buoy located at the Thunder Bay National Marine Sanctuary to researchers, educators, students and the public at widespread national locations over Internet2. The project will increase buoy wireless transmission bandwidth from 1.5 Mb/s to 43 Mb/s, implement a fiber connection to underwater networking equipment, demonstrate multicasting of digital video, and implement the Digital Video Transport System (DVTS) software on a LINUX processor operating in an underwater network hub. The DVTS demonstration

will include the first implementation of DVTS in an offshore underwater application. This project will attempt to advance the capabilities of the Thunder Bay National Marine Sanctuary (TBNMS) by demonstrating real-time underwater digital video viewed at TBNMS, Mystic Aquarium (Mystic, CT), and at Merit Network, Inc. (Ann Arbor, MI) using the Internet2 network.

The National Marine Sanctuary Program, administered by NOAA's National Ocean Service, manages and protects specially designated areas of the nation's oceans and Great Lakes for their habitats, ecological value, threatened and endangered species, and historic, archeological, recreational and esthetic resources. The Thunder Bay National Marine Sanctuary maintains stewardship over one of the nation's most historically significant collection of shipwrecks. Located in the northeast corner of Michigan's lower peninsula, the sanctuary contains hundreds of shipwrecks. Preserved by the cold, fresh water of Lake Huron, these submerged cultural resources are time capsules linking us to our collective maritime past. The sanctuary seeks to ensure that divers and non-divers of all ages share in the discovery, exploration and preservation of Thunder Bay's historic shipwrecks. The majority of sanctuary visitors experience these archeological resources at the Great Lakes Maritime Heritage Center, the TBNMS visitor's center, but are unable to have the sense of being "fully present" that is experienced by the diving public. An approach to sanctuary access is being taken through this advanced version of ReCON that will provide better access for a larger number of users at the TBNMS, other national marine sanctuaries, and other institutions.

The offshore network at TBNMS, *Figure 4*, will include a modified ReCON buoy located near Thunder Bay Island (TBI) in Lake Huron in the vicinity of a shipwreck, a relay and meteorological station located on TBI, and a shore station located at the Maritime Heritage Center in Alpena, MI. A digital video camera will be connected to a modified ReCON underwater hub and transferred to the surface over a fiber optic cable using 100BaseTX / 100BaseFX converters. The camera digital video output (IEEE-1394) will be converted to Ethernet (IEEE 802.3) using the DVTS software running on a LINUX processor located in the underwater hub.

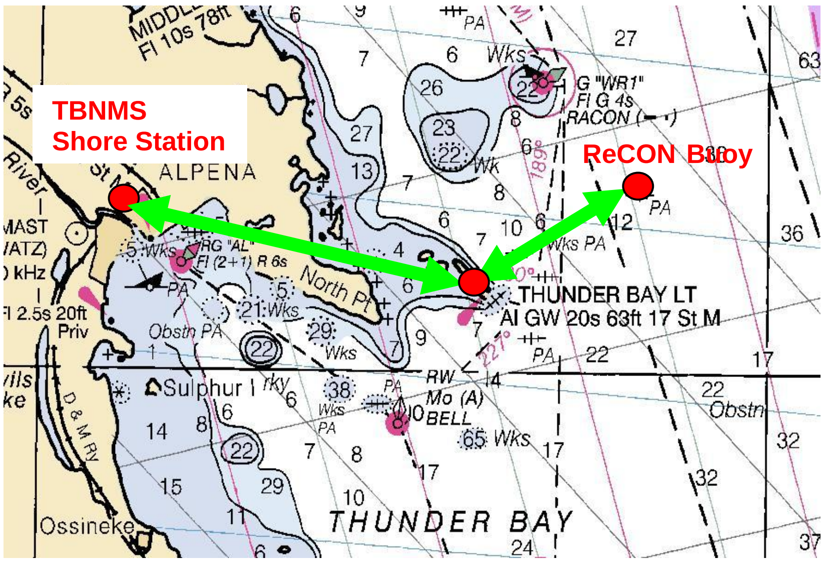

Figure 4. The next generation ReCON buoy will relay digital video and data over a 43 Mb/s, 5.8 GHz wireless, point-to-point link to the shore station located at the TBNMS visitors center. Underwater video from a shipwreck, requiring up to 30 Mb/s of system bandwidth, located on Lake Huron will be used for public and educational outreach.

IV. Summary

The technology successfully developed under the ReCON project represents a new model for real-time coastal observations that takes full advantage of modern networking technology. The ability to extend networks offshore through buoys and relay stations allows the use of software tools and techniques currently already developed and in widespread use today. The ability to leverage this pervasive technology has resulted in low system development costs while providing a high bandwidth system that is readily adaptable to meet the needs of forecasters, researchers, educators, and the public.

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